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Six-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

by
Robert D. Neathammer

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FOREWORD

This research was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC), under the following Intra Agency Orders (IAOs) from Fort Irwin and Headquarters, U.S. Army Forces Command (FORSCOM): FHAA022-83, dated August 1983; R039-84, dated May 1984; S040-85, dated January 1985; T016-86, dated November 1986; CERL-87, dated December 1987; CERL-88, dated June 1988; CERL-89, dated 2 March 1989; and Headquarters, U.S. Army Corps of Engineers (HQUSACE) FAD 90-080031, dated September 1990.

The USAEHSC technical monitor was Mr. Alex Houtzager (CEHSC-HM-O). Other technical advisors from USAEHSC were Mr. Robert Lubbert and Mr. Joe Hovell. Coordination and advice from FORSCOM were provided by Mr. Bill Mann, FCEN-RDM.

The work was performed by the Facility Systems Division (FS), U.S. Army Construction Engineering Research Laboratory (USACERL). The principal investigator was Mr. Robert Neathammer with assistance from Mr. Robert Doerr.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Congress believes that use of manufactured (factory built) military housing, rather than conventionally built units, will result in lower overall costs and provide durable housing meeting contemporary housing standards. To verify this belief, Congress directed the Department of Defense (DOD) to construct 200 units of manufactured housing at Fort Irwin, CA, and compare them with similarly designed, conventionally built housing.[1] DOD was also directed to perform a study comparing the operation and maintenance (O&M) costs of the two types of construction over a 5-year period.

Results of the 5-year study showed no difference in O&M costs between the two types of construction. However, the Assistant Secretary of Army for Installations, Logistics, and Environment, the U.S. Army Engineering and Housing Support Center (USAEHSC), and the U.S. Army Construction Engineering Research Laboratory (USACERL) all think 5 years is too short a time for valid comparisons of these types of costs. Thus, USACERL was requested to continue collecting and analyzing data and report results at the end of each year in order to identify broad trends.

The manufactured units met Federal Manufactured Housing Construction and Safety Standards (FMHCSS); however, upgrades in certain criteria were specified to bring the units into conformance with DOD standards. These areas of concern included net usable floor space, energy efficiency, fire and life safety, and durability of certain materials and components. The study compared the impact of the modified FMHCSS versus standard DOD criteria, except for the essential criteria listed above.

The study began when the housing units were first occupied; initial occupancy of some units started in February 1983. The study compares 200 two-bedroom manufactured units to 144 two-bedroom, conventionally built units. The two types of units were similar in floor area, floor plans and materials used. The conditions and parameters for this test were submitted to Congress.

The data collected address O&M costs for both types of housing. The study identifies not only the differences, if any, in O&M costs, but also the reasons for the differences and their importance for future construction criteria, and construction methods.

Objective

This report summarizes the O&M costs for both conventionally built and manufactured housing from construction through the first 6 years of occupancy.

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[1] Report No. 97-44, *Military Construction Authorization Act* (House of Representatives Committee on Armed Services, 1982), pp 8-9.

Approach

The first step was to develop uniform data collection and data analysis procedures. The cost comparisons and analyses for this study were established in USACERL Special Report (SR) P-140.[2] Data were collected throughout the study and summarized/reported yearly. First year data were reported in USACERL Interim Report (IR) P-85/14,[3] second year data in USACERL IR P-86/06,[4] third year data in USACERL IR P-87/10,[5] fourth year data in USACERL IR P-88/09,[6] 4 1/2 year data in USACERL IP P-89/14,[7] and fifth year data in USACERL TR P-90/11.[8]

Individuals were assigned to quarters with no distinction between the two types of units. The units all have the same floor area and were to be occupied by essentially the same ranks/ages of sponsors; i.e., the assignment of families was not biased by the type of construction.

Scope

Costs were limited to buildings themselves, as the intent of the study was to compare O&M costs of the two types of construction. Thus, sidewalks, driveways, streets, lawns, playgrounds, and utility lines outside the buildings were not included. Also, the replacement costs of refrigerators, kitchen stoves, and utility meters were excluded. (Because of these exclusions, the unit cost data in this report *is not comparable* to standard unit cost data reported for family housing in many Army financial reports, which normally includes costs such as streets and utilities.)

[2] M.J. O'Connor, *Fort Irwin Housing Comparison Test*, Special Report (SR) P-140/ADA130349 (USACERL, 1983).

[3] R.D. Neathammer, *Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, Interim Report (IR) P-85/14/ADA159740 (USACERL, 1985).

[4] R.D. Neathammer, *Two-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-86/06/ADA175995 (USACERL, 1986).

[5] R.D. Neathammer, *Three-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-87/10/ ADA180001 (USACERL, 1987).

[6] R.D. Neathammer, *Four-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-88/09/ADA190017 (USACERL, 1988).

[7] R.D. Neathammer, *May 1984 to September 1988 Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-89/14/ADA209421 (USACERL, 1989).

[8] R.D. Neathammer, *Five-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR P-90/11/ADA222176 (USACERL, 1990).

2 REVIEW OF TEST PLAN

This section gives a short review of the test plan and the final data analyses. Data were collected for O&M costs.

USACERL SR P-140 detailed the cost data collection plan and analysis methods. Four basic questions on costs will be answered:

1. Were the average annual O&M costs significantly different?

2. If different, where were they significantly different?

3. Why did the costs differ?

4. What criteria, design features, etc., need to be changed as a result?

Overall maintenance costs and utility costs were compared separately. If significant differences were found, it is important to determine their causes.

In addition to the overall cost comparison, the maintenance costs for major building components were compared. These comparisons provide more detail about where and why cost differences occur.

Occupant satisfaction with the overall apartments and each physical part of the unit was compared for the two types of construction and reported in USACERL P-90/11. When occupant satisfaction differed for a building component, that component was evaluated to determine the reason for the difference.

3 DESCRIPTION OF THE FAMILY HOUSING UNITS

Manufactured Housing Units (MHUs)

These 200 units consist of 50 two-story fourplexes (two units on each of the first and second floors). Net floor area is 950 sq ft/unit.* These were constructed on perimeter footing with wood floors and crawl spaces. Each upper unit has a balcony-porch and each lower one has a patio with privacy fencing. Figure 1 shows front and rear views of typical buildings. Each unit has a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace (all provided by the contractor). Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, and a one-car garage. The garage was constructed on site.

A detailed description of the construction process including photographs and floor plans for the units is shown in Appendix A.

The notice to proceed date was 10 January 1983. Initial occupancy was:

61	units	Dec 83
7	units	Jan 84
64	units	Feb 84
57	units	Apr 84
9	units	May 84
2	units	Jun 84

Conventionally Built Units (CBUs)

The 144 units consist of 13 sixplexes, 6 fiveplexes, and 9 fourplexes, all two-story buildings. Net floor area is 950 sq ft/unit. These units were constructed on perimeter footings with building slab. Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, either a fenced patio or balcony-porch (for upper unit), and a one-car garage. Figure 2 shows front and rear views of typical buildings. The fourplexes have two units on each level. There are two units on the second story in the five- and sixplexes with the additional unit(s) on the first level. The CBUs also have a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace.

The notice to proceed date was 3 May 1982. Initial occupancy was:

8	units	Feb 83
28	units	Mar 83
38	units	Apr 83
31	units	May 83
23	units	Jun 83
14	units	Jul 83
2	units	Aug 83

*Metric conversions: 1 cu ft = 0.028 m^3; 1 sq ft = 0.093 m^2; °C = 0.55 x (°F-32).

A detailed description of all units can be found in the Los Angeles District Office report.[9] The buildings were not specifically adapted to the desert environment but are typical Southern California design.

Costs

A clear cut initial cost comparison was not possible. The 144 CBUs were part of a 254 unit project. The cost for this project was $51.83/sq ft. The 200 MHUs costs were $51.22/sq ft. However, the supervision and administration costs for the MHUs were based on the same 5 percent rate used for the CBUs. More actual labor was required since quality assurance inspection was required at the manufacturing plant as well as at the construction site. It was estimated that the additional labor would have raised the cost to $55/sq ft (no records were kept as these are all indirect costs).

General Comparison

Fort Irwin is located in a high desert environment. Annual rainfall averages 4 in. and temperatures often exceed 100 °F. The housing construction was not adapted to this climate but is representative of Southern California design.

The exterior finish of both types is basically stucco. Exterior trim is painted wood. There is some brick veneer on the garages. Asphalt shingles were used on both types, and gutters and downspouts were installed.

On the interiors, walls are painted gypsum board. Floors on the second level are carpeted and are vinyl tile or vinyl sheet covering on the first floor.

Water piping is copper in the CBUs and polybutylene in the MHUs.

Windows are single pane in the MHUs and are thermal pane in the CBUs.

Floors in MHUs are wood on crawl spaces and in CBUs are concrete slabs.

Grass was planted in the immediate yard area of the buildings, but not in play yard areas. Each first floor unit has a concrete patio, each second story unit a wooden balcony-porch. There is a wooden privacy fencing for each first floor unit.

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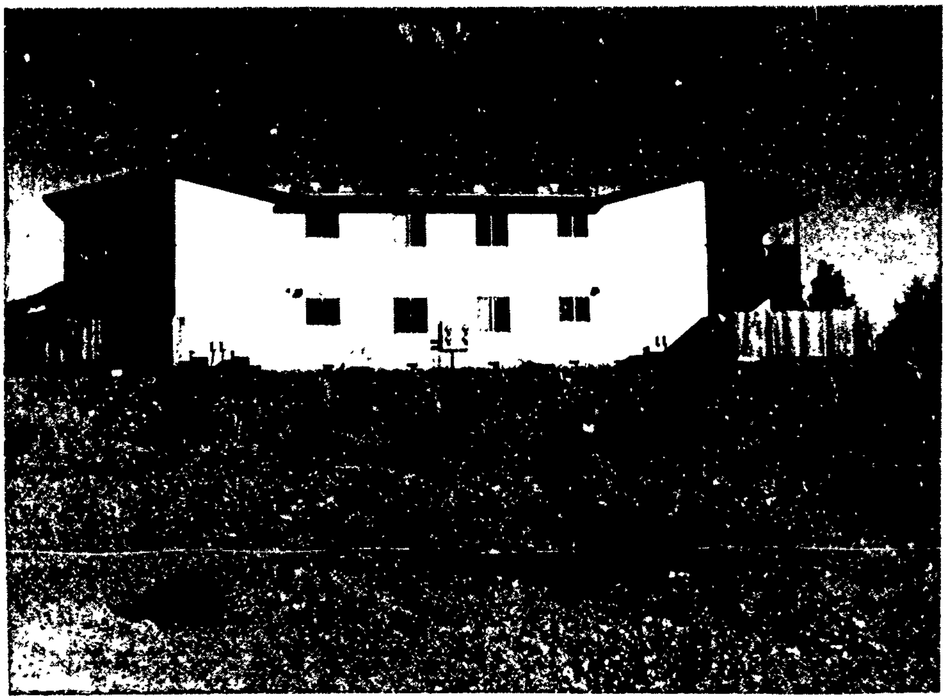
[9] *Fort Irwin Family Housing Study: A Report on Manufactured/Factory Built Housing and Site Built Housing, Fort Irwin, CA* (U.S. Army Corps of Engineers, Los Angeles District, September 1984).

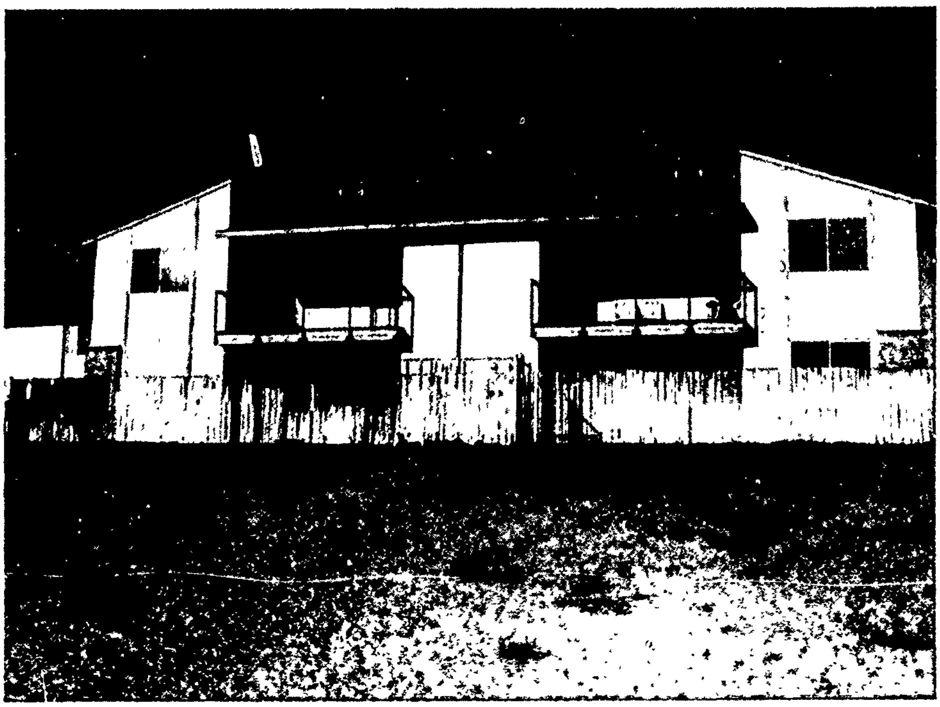
Front View - MHU



Rear View - MHU

Figure 1. Front and rear views of typical MHUs.

Front View - CBU



Rear View - CBU

Figure 2. Front and rear views of typical CBUs.

4 DATA COLLECTION PROCEDURES

Data were collected in enough detail that any differences found between the two types of construction could be explained. Appendix B lists the housing units and their identification numbers used in the data collection. Appendix C lists the building components and subcomponents. Each service order was coded to one of these so that costs of components could be compared. A discussion of the data collected is included in USACERL SR P-140.

Data Collection

Discussions were held with representatives of the USAEHSC technical monitor, Forces Command Headquarters, Fort Irwin personnel, and the base operations contractor, Boeing Services International (BSI), to establish the best methods of collecting the data.

BSI was contracted to segregate all service orders for maintenance for the test units and report cost data to USACERL through the Fort Irwin Directorate of Engineering and Housing (DEH) on a monthly basis. BSI was also contracted to read gas and electric meters at the end of each month and report similarly.

A new contractor, Dynalectron, became the base operations contractor effective 1 October 1986 and performed the same services described above.

Data Verification

USACERL verified the reported data several ways. For the first 5 years, each original work order (WO) document was checked against the reported data forwarded by the contractor. Discrepancies were resolved on verification visits to Fort Irwin. Additionally, the contractor set up separate accounting codes for the two groups of units and the total billed was compared to the total obtained from summing all the individual WO data. For year 6 the reported data was checked for obvious errors and these were resolved with the contractor. No detailed validation of each WO was made as the purpose of the continued study is to search for overall, large trends.

USACERL developed a computer program to compare gas and electricity meter readings. When apparently erroneous data occurred, the contractor was notified and corrections made.

Data Analysis

Maintenance Costs

Maintenance costs were compared on a unit-month basis and yearly basis. The data were also summarized by building component to determine if one or more components for one of the types of units had large maintenance costs. If so, the reasons for these costs were determined; i.e., what criteria or design features should be reviewed/changed?

Cost differences could have been caused by material quality, installation, differences inherent to manufactured or conventional construction, and possible errors in specifications for the two projects.

Warranty work referred to the construction contractor was not included in the cost comparison since no cost data were available or applicable, as it was not a cost to the government. However, the cost of a service call to assess a problem was included.

Energy Consumption

Gas and electricity consumption were compared on a unit-month basis and a yearly basis. Since most of the MHUs were not completed until May 1984, prior energy consumption data for the CBUs was not used in comparisons. (Energy consumption comparisons are only valid for the same time frame because of varying weather conditions.)

5 WHOLE HOUSE ENERGY TESTS

Energy evaluations of sample units of each type of construction were performed immediately after construction was completed on each of the two groups of housing and again after 5 years of occupancy. The objective was to determine if energy characteristics had changed over the 5-year period. Three whole-house energy tests were performed. Appendices D and E give details of the tests for the CBUs and MHUs, respectively.

House Tightness

The number of air changes per hour were measured with the following results:

	Immediately After Construction			After 5 Years		
Type	No. Units	Average Air Change Per Hour	Standard Deviation (%)	No. Units	Average Air Change Per Hour	Standard Deviation (%)
CBU	15	13.0	1.06	15	12.1	1.70
MHU	12	10.9	2.67	14	9.7	1.60

There was a statistically significant difference between the two types of construction for both the initial and 5-year tests, the MHUs being more airtight on the average. Neither type of unit changed significantly over the 5 years. These results indicate that the MHUs should have had less air infiltration/leakage.

Furnace Efficiency

The furnace efficiency results were as follows:

	Immediately After Construction			After 5 Years		
Type (%)	No. Units	Average Efficiency (%)	Standard Deviation (%)	No. Units	Average Efficiency (%)	Standard Deviation
CBU	13	66.2	6.24	14	64.2	12.2
MHU	16	79.3	3.36	15	77.3	2.84

The furnace efficiencies of the MHUs were significantly higher than those of the CBU for both the initial and 5-year tests. Neither type of unit changed significantly over the 5 years.

Wall Heat Transfer Characteristics

This parameter was not initially measured for the CBUs because of unfavorable weather during the testing period. This parameter was calculated for both types of construction using the designed wall construction.

Type	No. Units	Average Heat Loss (Btu/hr-°F)
CBU	16	1072
MHU	15	1220

Summary

The whole house energy tests did not conclusively indicate which type of unit would use less energy for heating/cooling. The CBUs are more energy efficient considering only the wall heat loss test, but the MHUs perform better when tested for air tightness and furnace efficiency. Additionally, the CBUs are built on concrete slabs while the MHUs have a crawl space. Concrete slabs are better (use less energy) than crawl spaces. This has an impact on the first floor units' energy use.

Thus the tests are inconclusive in predicting which type of construction would use more energy for heating/cooling.

6 OPERATION AND MAINTENANCE (O&M) COSTS

O&M costs for each type of unit were compared over the first 6 years of occupancy. For CBUs, this was 1 August 1983 through 31 July 1989 and for MHUs, 1 June 1984 through 31 May 1990.

Overall Costs

The total housing unit-months and maintenance costs for the first 6 years of occupancy are shown in Table 1. (Maintenance includes all types of repairs and "preventive maintenance" performed.)

Table 1

Unit/Month Costs in First 6 Years Occupancy

Type	No. Unit Months	Total Cost ($)	Cost/Unit/ Month ($)	Cost/Unit/ Year ($)
CBU	10,368	336,541	32.46	390
MHU	14,400	636,440	44.20	530

Discussion

The MHUs cost about $12/month more than the CBUs over the first 6 years of occupancy; the difference in cost per unit per year of an MHU is $140. There were large increases in M&R costs in years 4 and 5. This is illustrated in Table 2, which shows M&R c^sts per year of occupancy.

Table 2

Yearly M&R Costs by Type Construction

Year	Total CBU ($)	Cost/ Unit ($)	Total MHU ($)	Cost/ Unit ($)
1	31,592	219	34,164	171
2	29,107	202	59,076	295
3	44,391	308	63,717	319
4	45,565	316	114,728	574
5	89,186	619	188,563	943
6	96,700	672	175,633	878
6-Year Total	336,541	390	636,440	530

Costs per unit have been increasing over time. Figure 3 shows the cumulative cost per unit per month for ages 15 to 72 months, illustrating this trend. The costs for the MHUs increased slightly faster than for the CBUs. This can also be seen in Figure 4, which shows costs per unit per year.

Increased costs in years 4 and 5 were attributable mainly to interior painting done in units vacated for the first time and in those which required painting on change of occupancy. Table 3 shows the painting costs per year of occupancy. Note the large increases for MHUs in year 5 and for CBUs in year 6. Painting costs for the MHUs may have stablized in year 6.

Table 3

Interior Painting Costs

Year	Total CBU ($)	Cost/ Unit ($)	Total MHU ($)	Cost/ Unit ($)
1	603	4	259	1
2	1,288	9	4,684	23
3	7,312	51	13,741	69
4	11,537	80	24,386	122
5	29,779	207	80,499	402
6	49,481	344	74,870	374
6-Year Total	100,000	116	198,439	165

Table 4 shows the yearly costs excluding interior painting. This table shows that the MHUs' costs increased slightly faster than did the CBUs through year 5. Both showed a decrease in year 6. Figure 5 displays this data.

Table 4

Yearly M&R Costs Excluding Interior Painting Costs

Year	Total CBU ($)	Cost/ Unit ($)	Total MHU ($)	Cost/ Unit ($)
1	30,989	215	33,905	170
2	27,819	193	54,392	272
3	37,079	257	49,976	250
4	34,028	236	90,342	452
5	59,407	413	108,064	540
6	47,209	328	100,763	504

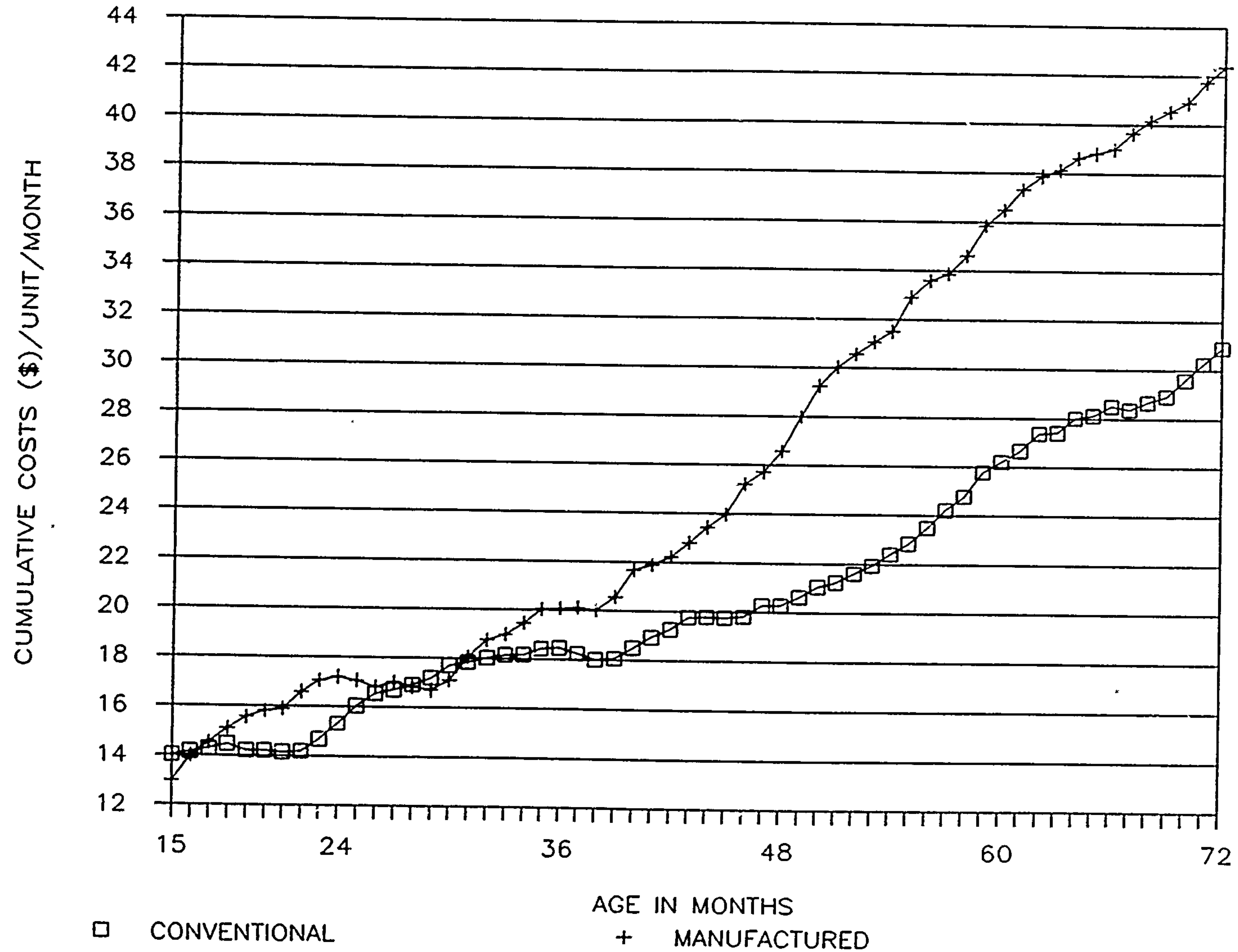


Figure 3. Cumulative cost per unit per month for ages 15 through 72 months.

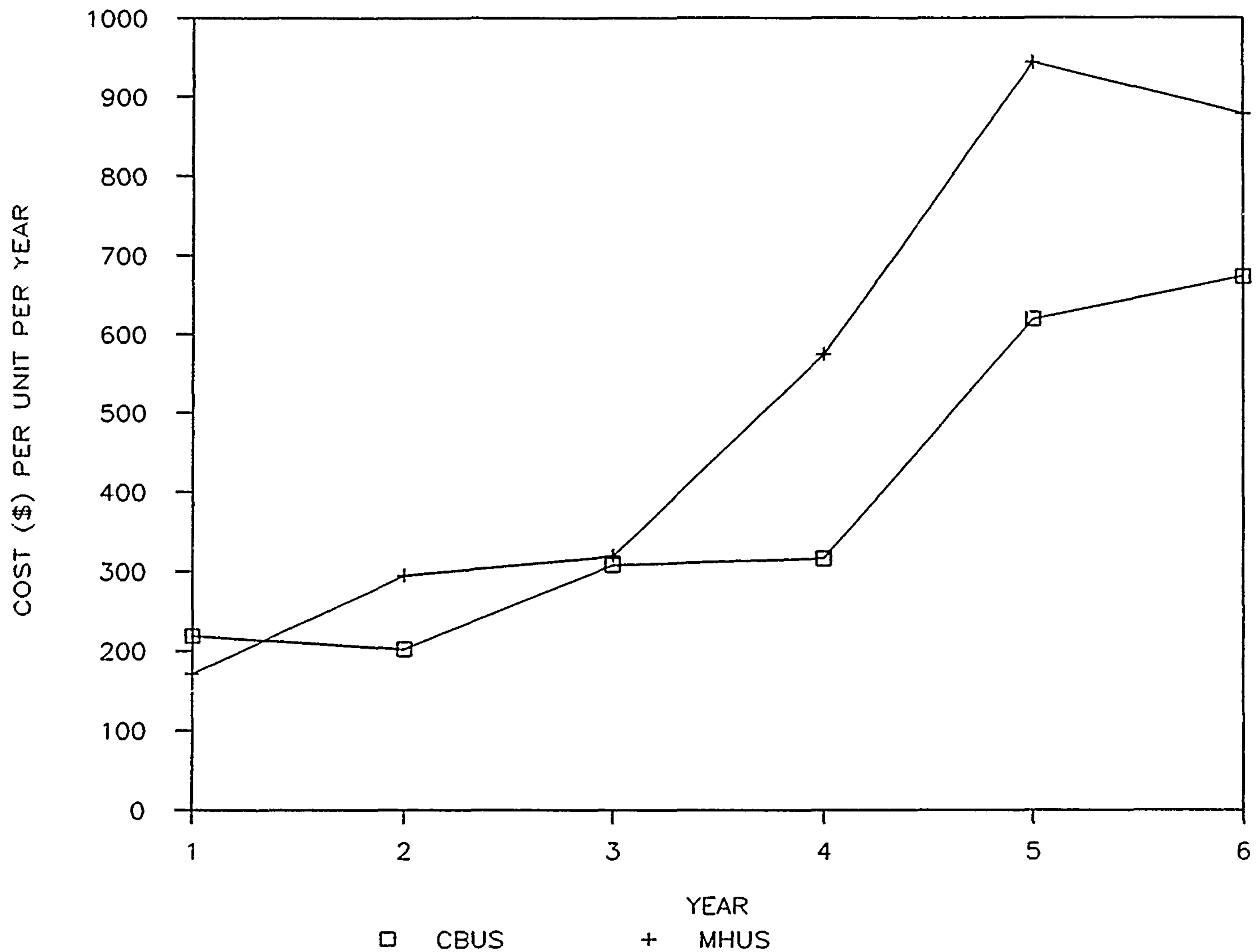


Figure 4. Total costs per unit per year.

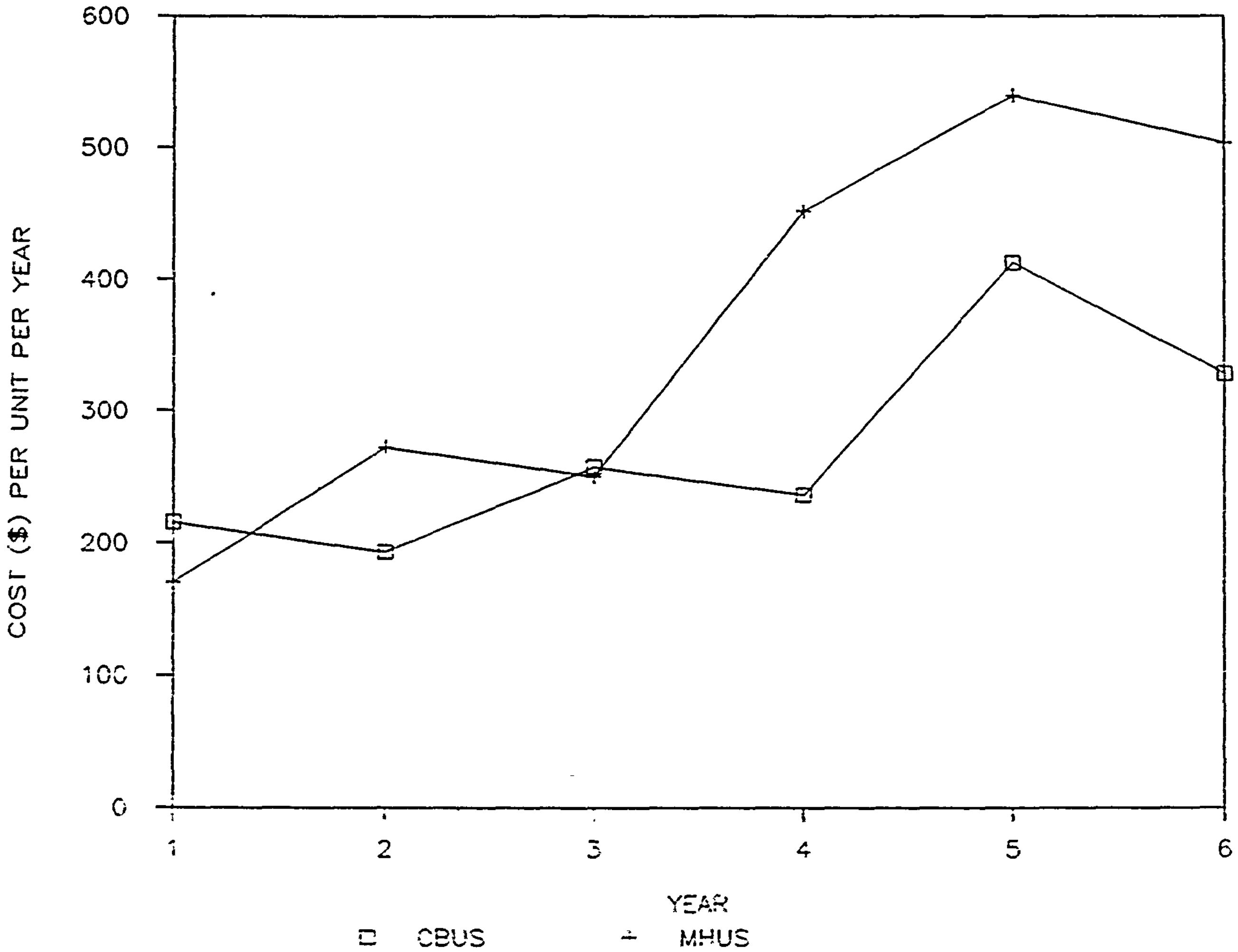


Figure 5. Costs per unit per year excluding interior painting costs.

Costs Excluding Certain Equipment Costs

Since the purpose of this study was to compare maintenance costs attributable to method of construction, another table was generated excluding certain costs. Table 5 gives the costs for the 6 years of occupancy of each type unit, excluding any costs for maintenance of water heaters, garbage disposals, dishwashers, ranges, range hoods, and refrigerators (equipment not part of the construction process).

Table 5

Unit Costs Excluding Certain Equipment Costs

Year	Total CBU ($)	Cost/ Unit ($)	Total MHU ($)	Cost/ Unit ($)
1	25,570	178	26,279	131
2	25,128	174	48,416	242
3	37,275	259	53,789	269
4	40,465	281	96,381	482
5	80,998	562	164,253	821
6	90,662	630	146,501	732
6-Year Total	300,099	347	535,619	446

The difference in cost per unit per year between types of construction is $99/year. Compared to the $140 in Table 1, this is a better estimate of the cost difference attributable to the type of construction.

Costs Excluding Interior Painting and Equipment Costs

In Table 6 equipment costs and painting costs are excluded.

Table 6

Unit Costs Excluding Certain Equipment and Painting Costs

Year	CBU	MHU	CBU	MHU
1	24,967	25,962	173	130
2	23,840	43,732	166	219
3	29,963	40,048	208	200
4	28,928	71,995	201	360
5	51,219	83,754	356	419
6	41,181	71,631	286	358
6-Year Total	200,098	337,122	231	281

The difference for unit cost is $50 per year. Figure 6 graphs the data of Table 6.

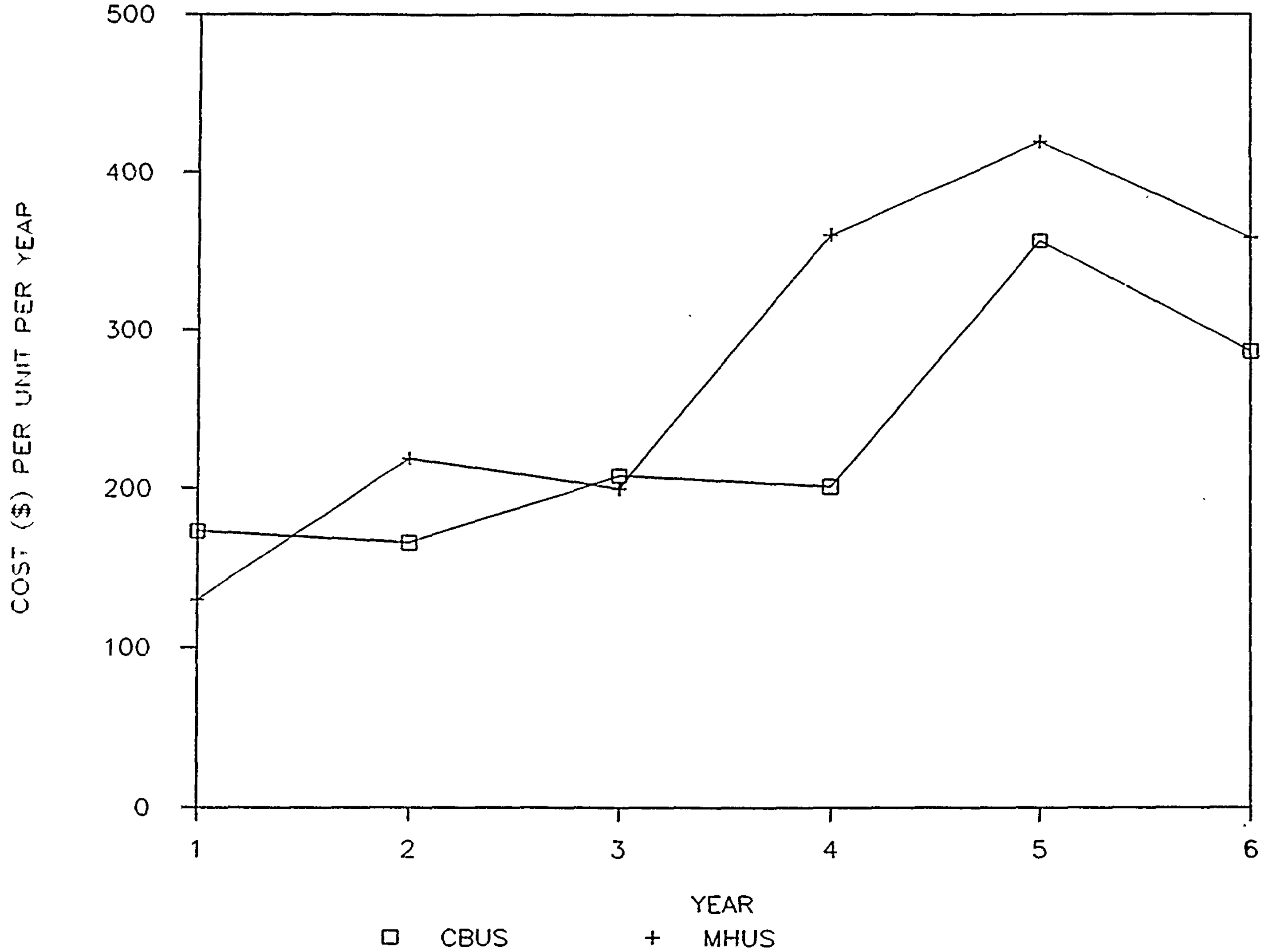


Figure 6. Costs per unit per year excluding certain equipment and painting costs.

Frequencies of Maintenance Per Housing Unit

For the MHUs, the number of WOs for a housing unit ranged from 5 to 75. For the CBUs, the range was from 10 to 77. Table 7 lists the frequencies.

Table 7

Frequency of Maintenance Actions

MHU		CBU	
No. of WOs Totals	No. of Units With These Totals	No. of WOs	No. of Units With These
120+	14 (10)*	120+	4
110-119	16 (12)	110-119	7
100-109	23 (17)	100-109	6
90-99	35 (25)	90-99	13
80-89	36 (26)	80-89	22
70-79	34 (24)	70-79	21
60-69	19 (14)	60-69	25
50-59	19 (7)	50-59	27
40-49	7 (5)	40-49	6
1-39	2 (1)	1-39	6

*Number in parentheses is computed by multiplying number of units by 0.72(144/200) for comparison to CBUs.

It should be noted that the "number of work orders" refers to the number of component actions. Whenever a change of occupancy occurs, numerous building components were repaired—there was one official WO number, but each component action was considered a WO for analysis. This can be seen in Table 8.

Table 8

Component Actions and Work Orders

	MHU			CBU		
Year	Number Component Actions	Number WOs	Average Number WOs/Unit	Number Component Actions	Number WOs	Average Number WOs/Unit
Year 1	1,718	1,610	8	1,139	1,128	8
Year 2	1,938	1,371	7	989	863	6
Year 3	2,183	1,273	6	1,404	877	6
Year 4	4,048	1,867	9	1,592	869	6
Year 5	3,735	2,028	10	2,920	1,335	9
Year 6	3,830	2,116	11	2,506	1,247	9
Total	17,452	10,265	51	10,600	6,319	44

Maintenance Per Component

Table 9 lists the frequencies of work orders and costs per building component for the two types of units. However, the costs were not directly comparable across the two types of units since there were 200 MHUs and 144 CBUs. Table 9 shows the cost data adjusted by multiplying the MHU costs by 0.72 (144/200). Also shown in Table 9 are the 6-year costs on a unit basis.

Table 10 shows that the total cost was less than $500 for both types for 20 of the 78 components. For 42 of the other 58 components, the MHUs had a higher cost.

Most of the costs shown in Tables 9 and 10 were for building components independent of type of construction. For example, over $12K was spent on the ranges for each type unit, $12K for CBUs and $52K for MHUs was spent on dishwashers, over $15K on light fixtures for each type, etc. The most significant costs for components which differ for the types were roofing surface, doors/frames, storm windows and screens, and piping. Although a large difference existed for painting, this cost depended on rotation of occupants and occupant wear and tear. Complete quarters painting was done on 223 MHUs and only 114 CBUs.

Note the $17,767 cost for exterior-trim painting of MHUs and $0 for CBUs. The exterior trim was to be painted on a cyclic basis. The CBU cycle in 1988 was deferred. Both CBU and MHU exterior-trim painting for 1989 was deferred.

One difference in the construction of the two types was the use of copper piping for the CBUs and polybutylene for the MHUs. There have been two major breaks in a "tee" joint in the ceiling of the first floor units of the MHUs. A detailed analysis of plumbing service orders shows a higher cost for MHUs for the category leaking or broken piping. Costs for each of the 6 years are shown below:

Year	CBUs ($)	MHUs ($)
1	525	785
2	471	2146
3	358	511
4	440	1391
5	52	2242
6	349	4516
Total	2196	11,592

Table 11 summarizes Table 10 data into the 12 major building component codes (Appendix C). Although the 0201-0220 structure is a high cost item, Table 10 shows most of these costs are doors and windows related and much of the damage to these items was occupant caused.

Table 9

Maintenance Actions Performed and Costs Per Component

Component		Maintenance/Repair Actions				Cost ($)			
No.	Description	CBU (N=10,600)*		MHU (N=17,452)		CBU (Total= 336,541)		MHU (Total= 636,440)	
101	Roofing surface	110	(1%)**	312	(2%)	8940	(3%)	26419	(4%)
103	Flashing, vents	12		7		322		385	
104	Gutters and downspouts	228	(2%)	312	(2%)	3471	(1%)	4643	(1%)
105	Other roof repairs	0		2		0		16	
201	Foundation and anchorage	3		2		24		24	
202	Structure	15		55		227		1780	
203	Insulation	3		0		42		0	
204	Masonry	9		7		221		161	
205	Exterior siding	4		2		207		238	
206	Exterior doors and frames	357	(3%)	646	(4%)	6735	(2%)	13811	(2%)
207	Storm and screen doors	504	(5%)	760	(4%)	14951	(4%)	25824	(4%)
208	Windows and frames	126	(1%)	193	(1%)	2616	(1%)	4170	(1%)
209	Storm windows and screens	246	(2%)	249	(1%)	4692	(1%)	4188	(1%)
210	Exterior trim	0		2		0		26	
211	Porch/deck	2		2		32		87	
212	Interior drywall	143	(1%)	281	(2%)	3922	(1%)	8925	(1%)
213	Wall coverings and paneling	11		1		200		2	
214	Interior doors	956	(9%)	1157	(7%)	17344	(5%)	16153	(3%)
215	Interior casework	38		61		492		840	
216	Bathroom accessories	129	(1%)	180	(1%)	2228	(1%)	1779	
217	Kitchen accessories, cabinets	215	(2%)	396	(2%)	2945	(1%)	5133	(1%)
218	Drapery hardware	13		71		221		877	
219	Other exterior/interior	155	(1%)	222	(1%)	3932	(1%)	4977	(1%)
220	Garage doors	484	(5%)	412	(2%)	9941	(3%)	6452	(1%)
301	Resilient flooring	47		234	(1%)	1590		4634	(1%)
302	Carpet and pad	8		25		105		1671	
304	Underlayment/substrate	2		6		13		70	
305	Other flooring	24		53		933		3596	(1%)
401	Paint, walls and ceilings	182	(2%)	282	(2%)	97993	(29%)	194142	(31%)
402	Paint, trim	1		0		20		0	
403	Paint, touchup, interior	46		126	(1%)	1388		3437	(1%)
404	Bathtub, shower caulking	132	(1%)	270	(2%)	1389		2816	
405	Other interior painting	26		20		588		918	
501	Paint, exterior walls	3		3		92		45	
502	Paint, exterior doors, frames	5		4		138		79	
503	Paint, exterior trim	0		13		0		17767	(3%)
504	Exterior caulking	0		1		0		20	
506	Other exterior painting	2		3		44		75	

*N = Number of maintenance actions

**Percents are given for number maintenance actions and costs when the value is 1% or more of the total.

Table 9 (Cont'd)

Component No.	Description	Maintenance/Repair Actions CBU		MHU		Cost ($) CBU		MHU	
601	Heating plant, valve	96	(1%)	53		2995	(1%)	2718	
602	Motors, blowers, pumps	53	(1%)	81		3576	(1%)	5330	(1%)
603	Ducts	1		20		15		1042	
604	Piping	6		1		174		16	
605	Diffusers, grills	11		65		173		920	
607	Heating controls	118	(1%)	92	(1%)	4640	(1%)	3706	(1%)
608	Other heating	390	(4%)	663	(4%)	5340	(2%)	8104	(1%)
701	Cooling coils, compressor	34		38		6050	(2%)	2070	
702	A/C motors, blowers, pumps	89	(1%)	112	(1%)	6582	(2%)	5163	(1%)
703	A/C piping, ducting	6		31		160		973	
704	A/C refrigerant	369	(3%)	199	(1%)	12960	(4%)	6861	(1%)
705	A/C insulation	1		0		7		0	
706	A/C controls	87	(1%)	82		3610	(1%)	3126	
707	Other cooling	429	(4%)	607	(3%)	6085	(2%)	8793	(1%)
801	Water heater	217	(2%)	395	(2%)	4502	(1%)	12197	(2%)
803	Piping, supply	117	(1%)	438	(3%)	3971	(1%)	15892	(2%)
804	Faucets and shower heads	431	(4%)	1184	(7%)	9125	(3%)	25126	(4%)
805	Lavatories	262	(3%)	640	(4%)	3992	(1%)	16163	(3%)
806	Water closets	565	(5%)	914	(5%)	10293	(3%)	16321	(3%)
807	Bathtub/shower unit	76	(1%)	319	(2%)	1144		6119	(1%)
809	Other plumbing	127	(1%)	277	(2%)	2286	(1%)	5468	(1%)
901	Service entrance	2		2		65		188	
902	Panel box/circuit breakers	51		142	(1%)	1554		4683	(1%)
903	Branch circuits	16		21		423		1358	
904	Wall receptacles	236	(2%)	405	(2%)	3172	(1%)	6144	(1%)
905	Doorbells and chimes	0		1		0		4	
906	Light fixtures	933	(9%)	975	(6%)	15365	(5%)	15489	(2%)
907	Vents, fans	29		29		520		425	
908	Other electrical	35		34		733		2099	
1001	Garbage disposal	267	(3%)	544	(3%)	5259	(2%)	10804	(2%)
1002	Dishwasher	239	(2%)	772	(4%)	11858	(4%)	51995	(8%)
1003	Range	573	(5%)	982	(6%)	12749	(4%)	17738	(3%)
1004	Range hood	38		58		664		672	
1005	Refrigerator	81	(1%)	275	(2%)	1409		7976	(1%)
1006	Other equipment	115	(1%)	211	(1%)	1137		2050	
1201	Water supply	65	(1%)	111		1128		3512	(1%)
1202	Gas supply	66	(1%)	117	(1%)	2146	(1%)	3163	
1203	Electrical service	39		48		1212		3971	(1%)
1204	Sanitary/sewer lines	5		4		657		191	
1205	Other utility service	0		1		0		8	
1300	Miscellaneous	83	(1%)	137	(1%)	779		1405	

Table 10

Maintenance Costs Per Component, Adjusted by Number of Units

Component		Costs ($)				
No.	Description	CBU	MHU	MHU Adjusted*	CBU/144**	MHU/200**
101	Roofing surface	8940	26419	19022	62.08	132.10
103	Flashing, vents	322	385	277	2.24	1.93
104	Gutters and downspouts	3471	4643	3343	24.10	23.22
105	Other roof repairs	0	16	12	0.00	0.08
201	Foundations and anchorage	24	24	17	0.17	0.12
202	Structure	227	1780	1282	1.58	8.90
203	Insulation	42	0	0	0.29	0.00
204	Masonry	221	161	116	1.53	0.81
205	Exterior siding	207	238	171	1.44	1.19
206	Exterior doors and frames	6735	13811	9944	46.77	69.06
207	Storm and screen doors	14951	25824	18593	103.83	129.12
208	Windows and frames	2616	4170	3002	18.17	20.85
209	Storm windows and screens	4682	4188	3015	32.58	20.94
210	Exterior trim	0	26	19	0.00	0.13
211	Porch/deck	32	87	87	0.22	0.44
212	Interior drywall	3922	8925	6426	27.24	44.63
213	Wall coverings and paneling	200	2	1	1.39	0.01
214	Interior doors	17344	16153	11630	120.44	80.77
215	Interior casework	492	840	605	3.42	4.20
216	Bathroom accessories	2228	1779	1281	15.47	8.90
217	Kitchen accessories, cabinets	2945	5133	3696	20.45	25.67
218	Drapery hardware	221	877	631	1.53	4.39
219	Other exterior/interior	3932	4977	3583	27.31	24.89
220	Garage doors	9941	6452	4645	69.03	32.26
301	Resilient flooring	1590	4934	3552	11.04	24.67
302	Carpet and pad	105	1671	1203	0.73	8.36
304	Underlayment/substrate	13	70	50	0.09	0.35
305	Other flooring	933	3596	2589	6.48	17.98
401	Paint, walls and ceilings	97993	194142	139782	680.51	970.71
402	Paint, trim	20	0	0	0.14	0.00
403	Paint, touchup, interior	1388	3437	2475	9.64	17.19
404	Bathtub, shower caulking	1389	2816	2028	9.65	14.08
405	Other interior painting	588	918	661	4.08	4.59
501	Paint, exterior walls	92	45	32	0.64	0.23
502	Paint, exterior doors, frames	138	79	57	0.96	0.40
503	Paint, exterior trim	0	17767	12791	0.00	88.84
504	Exterior caulking	0	20	14	0.00	0.10
506	Other exterior painting	44	75	54	0.31	0.38
601	Heating plant, valve	2995	2718	1957	20.80	13.59
602	Motors, blowers, pumps	3576	5330	3838	24.83	26.65

*The MHU column adjusted by multiplying by 0.72.

**These are costs per unit for the 6 years.

Table 10 (Cont'd)

Component No.	Description	CBU	MHU	MHU Adjusted	CBU/144	MHU/200
603	Ducts	15	1042	750	0.10	5.21
604	Piping	174	16	12	1.21	0.08
605	Diffusers, grills	173	920	662	1.20	4.60
607	Heating controls	4640	3706	2668	32.22	18.53
608	Other heating	5340	8104	5835	37.08	40.52
701	Cooling coils, compressor	6050	2070	1490	42.01	10.35
702	A/C motors, blowers, pumps	6582	5163	3717	45.71	25.82
703	A/C piping, ducts	160	973	701	1.11	4.87
704	A/C refrigerant	12960	6861	4940	90.00	34.31
705	A/C insulation	7	0	0	0.05	0.00
706	A/C controls	3610	3126	2251	25.07	15.63
707	Other cooling	6085	8793	6331	42.26	43.97
801	Water heater	4502	12197	8782	31.26	60.99
803	Piping, supply	3971	15892	11442	27.58	79.46
804	Faucets and shower heads	9125	25126	18091	63.37	125.63
805	Lavatories	3992	16163	11637	27.72	80.82
806	Water closets	10293	16321	11751	71.48	81.61
807	Bathtub/shower unit	1144	6119	4406	7.94	30.60
809	Other plumbing	2286	5468	3937	15.88	27.34
901	Service entrance	65	188	135	0.45	0.94
902	Panel box/circuit breakers	1554	4683	3372	10.79	23.42
903	Branch circuits	423	1358	978	2.94	6.79
904	Wall receptacles	3172	6144	4424	22.03	30.72
905	Doorbells and chimes	0	4	3	0.00	0.02
906	Light fixtures	15365	15489	11152	106.70	77.45
907	Vents, fans	520	425	306	3.61	2.13
908	Other electrical	733	2099	1511	5.09	10.50
1001	Garbage disposal	5259	10804	7779	36.52	54.02
1002	Dishwasher	11858	51975	37422	82.35	259.88
1003	Range	12749	17738	12771	88.53	88.69
1004	Range hood	664	672	484	4.61	3.36
1005	Refrigerator	1409	7976	5743	9.78	39.88
1006	Other equipment	1137	2050	1476	7.90	10.25
1201	Water supply	1128	3512	2529	7.83	17.56
1202	Gas supply	2146	3163	2277	14.90	15.82
1203	Electrical service	1212	3971	2859	8.42	19.86
1204	Sanitary/sewer lines	657	191	138	4.56	0.96
1205	Other utility service	0	8	6	0.00	0.04
1300	Miscellaneous	779	1405	1012	5.41	7.03
	Totals	336,541	636,440	458,237		

Costs ($) spans columns CBU through MHU/200.

Table 11

Maintenance Actions Performed and Costs for Component Group 6-Year Summary

Component Group	Description	Maintenance/Repair Actions CBU (N=10,600)		Maintenance/Repair Actions MHU (N=17,452)		Cost ($) CBU (Total = 336,541)		Cost ($) MHU (Total = 636,440)		Cost ($) MHU Adjusted (Total = 458,237)
0101-0105	Roofing	350	(3%)	633	(4%)	12,733	(4%)	31,463	(5%)	22,653
0201-0220	Structure	3,414	(32%)	4,699	(27%)	70,972	(21%)	95,444	(15%)	68,720
0301-0305	Floor coverings	81	(1%)	318	(2%)	2,640	(1%)	10,270	(2%)	7,394
0401-0405	Interior painting	387	(4%)	698	(4%)	101,389	(30%)	201,312	(32%)	144,945
0501-0506	Exterior painting	10	(0%)	24	(0%)	274	(0%)	17,986	(3%)	12,950
0601-0608	Heating	675	(6%)	975	(6%)	16,912	(5%)	21,836	(3%)	15,722
0701-0707	Air conditioning	1,015	(10%)	1,069	(6%)	35,453	(11%)	26,956	(4%)	19,408
0801-0809	Plumbing	1,795	(17%)	4,167	(24%)	35,315	(10%)	97,286	(15%)	70,046
0901-0908	Electrical	1,302	(12%)	1,609	(9%)	21,853	(6%)	30,391	(5%)	21,882
1001-1006	Equipment	1,313	(12%)	2,842	(16%)	33,077	(10%)	91,226	(14%)	65,683
1201-1205	Utility service	175	(2%)	281	(2%)	5,144	(2%)	10,845	(2%)	7,808
1300	Miscellaneous	83	(1%)	137	(1%)	779	(0%)	1,405	(0%)	1,012

Impact of Inflation on Comparisons

All of the costs in Table 11 were charged at the time of occurrence. There was about a 1-year difference between the two types of units since the CBUs were occupied about 1 year earlier than the MHUs. To assess the impact of inflation on the overall comparisons, costs were all converted to 1990 prices by multiplying total costs in a given year by that year's inflation factor. Inflation factors for the years 1983 through 1990 were determined from "The Home Maintenance and Repair Index" in the *Economic Report of the President* (Table B-59, Consumer Price Indexes, selected classes, 1946-1990, Jan 90). The yearly indices and inflation factors used in this study are shown below:

Year	Index	Inflation Factor
1990	121.5	1.000
1989	118.0	1.030
1988	114.7	1.059
1987	111.8	1.087
1986	107.9	1.126
1985	106.5	1.141
1984	103.7	1.172
1983	99.9	1.216

Figure 7 shows cumulative inflated costs per unit over time. This is the same graph as that in Figure 2, except that the costs are inflated. Note that the difference between the two types at the end of 5 years was about the same, but the magnitude of both had increased. This can also be seen in Table 12.

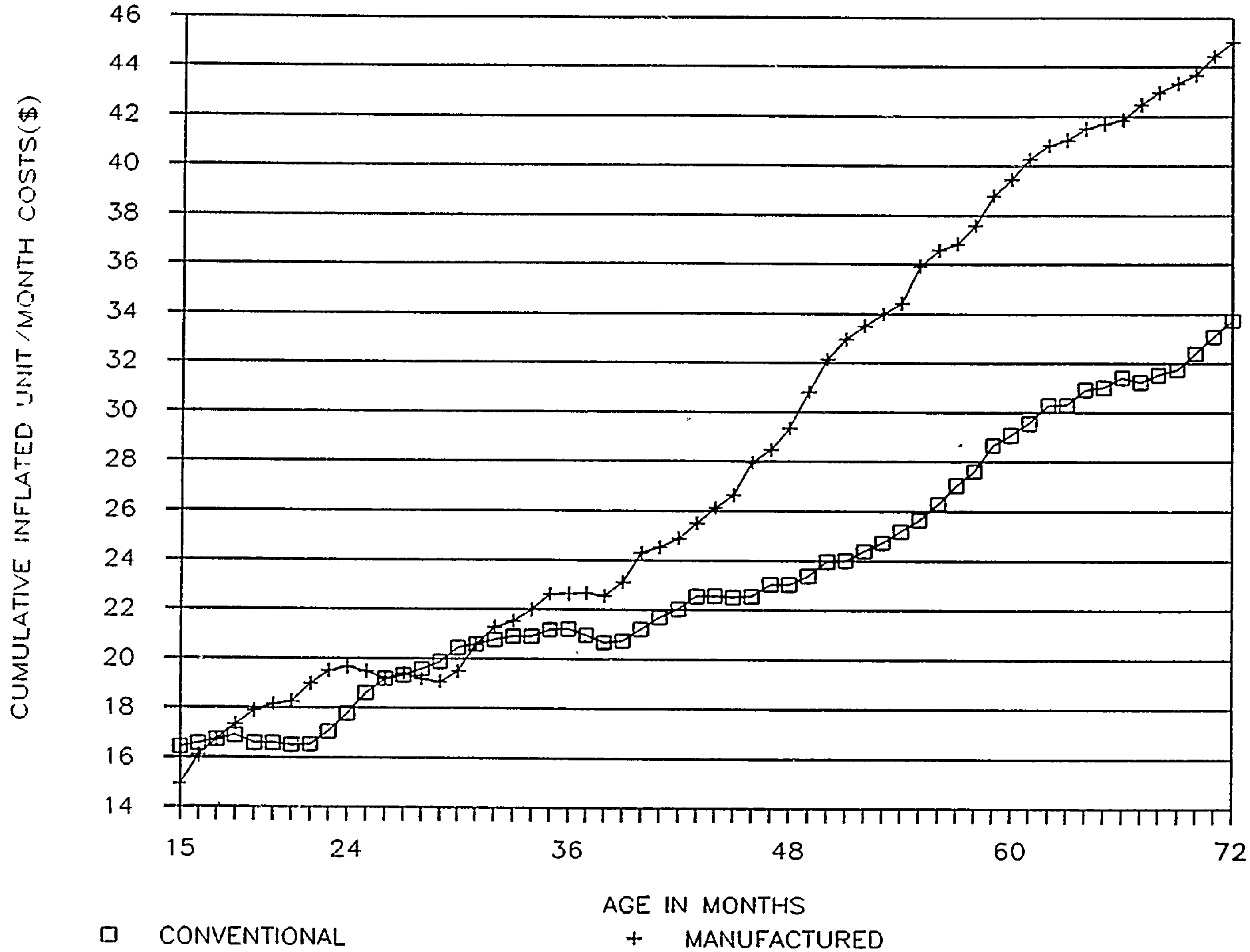


Figure 7. Cost per unit per month over time, adjusted for inflation.

Table 12

Comparison of Actual and Inflated Costs

Type	No. Unit Months	Total Cost ($)	Cost/Unit/ Month ($)	Cost/Unit/ Year ($)
CBU	10,368	336,541	32.46	390
CBU-Infl	10,368	366,902	35.39	425
MHU	14,400	636,440	44.20	530
MHU-Infl	14,400	676,472	46.98	564

The difference for cost/unit/year is $140 for actual costs and $139 for inflated costs. Thus, there is no difference in the two comparisons.

7 ENERGY COSTS

Comparisons of gas and electricity consumption began in May 1984, since most MHUs were not occupied before then.

Electricity Consumption

The average usage (kWh) per housing unit is shown in Table 13. For the entire 72-month data collection period, an MHU used an average total of 54,836 kWh, while a CBU used an average total of 54,032 kWh. This was a difference of 804 kWh ÷ 72 months = 11.17 kWh/month. At the November 1990 rate of $0.0953/kWh, an MHU cost $1.06 more than a CBU for electricity per month.

Gas Consumption

The type of fuel used was liquid propane (LP). LP is delivered to a central facility on post and is converted to gas and distributed to housing units through underground pipes. The average monthly usage (cu ft) per housing unit is shown in Table 14.

For the 72-month period, an MHU used an average total of 116,080 cu ft while a CBU used an average total of 109,608 cu ft. This is a difference of 6,472 cu ft ÷ 72 months = 90 cu ft/month. At the November 1990 cost of $0.01665/cu ft an MHU cost $1.50 more than a CBU for gas per month.

Cost Comparison Summary

The averages for dwelling unit energy consumption and cost for the 6-year period (May 1984 to April 1990) are given in Table 15. The MHUs on the average have cost $31 more per year for gas and electricity than the CBUs.

Meter Problems

Many meters have become defective over the past 6 years. For the CBUs 31 electric and nine gas meters have failed while for the MHUs 14 electric and four gas have failed.

Comments

The data in Chapter 5 (better air tightness and higher furnace efficiencies for the MHUs) would indicate the MHUs should use less energy than the CBUs. However, this is offset by the higher overall heat loss of the MHUs. Detailed energy simulations (performed using the Building Loads Analysis and

Table 13

Average Monthly Electricity Consumption (kWh) Per Housing Unit

		1984 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1985 Jan	Feb	Mar	Apr	Monthly Avg
Year 1	MHU	781	1007	1219	1264	1001	558	446	486	485	428	423	634	727
	CBU	704	960	1171	1132	908	583	434	471	464	418	444	550	687

		1985 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	Monthly Avg
Year 2	MHU	680	1180	1452	1421	644	574	525	514	508	448	466	468	740
	CBU	661	1014	1426	1312	700	610	547	493	482	435	465	484	719

		1986 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	Monthly Avg
Year 3	MHU	829	1149	1281	1521	746	572	460	571	500	429	474	592	760
	CBU	789	1071	1270	1335	857	633	451	607	510	512	492	639	767

		1987 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	Monthly Avg
Year 4	MHU	660	1033	1169	1442	1009	679	503	520	476	487	464	470	743
	CBU	679	1060	1265	1227	1099	755	568	515	494	485	520	476	761

		1988 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	Monthly Avg
Year 5	MHU	766	964	1336	1438	1013	823	530	506	550	494	490	697	801
	CBU	771	885	1220	1406	1019	845	581	530	580	501	543	678	796

		1989 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	Monthly Avg
Year 6	MHU	809	1079	1505	1311	969	714	500	555	484	489	555	598	798
	CBU	804	1046	1375	1208	941	720	510	525	478	476	522	645	773

Table 14

Average Monthly Gas Consumption (cu ft) Per Housing Unit

		1984 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1985 Jan	Feb	Mar	Apr	Monthly Avg
Year 1	MHU	900	680	580	630	580	1410	2410	3560	3550	2940	2710	1470	1787
	CBU	710	640	540	600	540	1110	2080	3190	3220	2790	2390	1280	1591
		1985 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	Monthly Avg
Year 2	MHU	950	610	620	660	710	1050	2680	2850	2550	2270	1710	1390	1504
	CBU	830	570	590	680	660	890	2420	2560	2400	2120	1680	1370	1398
		1986 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	Monthly Avg
Year 3	MHU	920	570	610	620	850	1210	1750	3330	3410	2600	2520	1070	1623
	CBU	900	660	740	730	830	1110	1580	3090	3310	2670	2530	1160	1612
		1987 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	Monthly Avg
Year 4	MHU	800	660	630	620	600	680	2020	3920	3320	2690	2040	1460	1621
	CBU	800	790	690	680	690	710	2120	3530	3380	2620	1990	1340	1605
		1988 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	Monthly Avg
Year 5	MHU	1240	680	560	640	660	720	2110	3170	3760	3070	1790	910	1608
	CBU	1130	660	620	680	680	740	1830	2830	3600	2970	1760	870	1533
		1989 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	Monthly Avg
Year 6	MHU	1000	640	640	650	630	1110	1670	3020	3050	3010	2000	960	1531
	CBU	920	630	650	680	650	990	1500	2590	2830	2750	1800	800	1396

System Thermodynamics* program) indicate two design/construction features that cause the higher wall-heat loss: the MHUs have more window/door glass area; and the MHUs have single-pane glass while the CBUs have thermal-pane. Additionally, the CBUs were built on concrete slabs while the MHUs have crawl spaces, which are less energy efficient.

Table 15

Six-Year Summary of Energy Consumption

	MHU		CBU	
Unit	**Gas**	**Electricity**	**Gas**	**Electricity**
Average Consumption/Year Per Housing Unit	19,346 cu ft	9,139 kWh	18,268 cu ft	9,005 kWh
Average Cost/Year Per Housing Unit	$322	$871	$304	$858

*Building Loads Analysis and System Thermodynamics (BLAST) was developed by USACERL and is used throughout the Department of Defense for military construction projects.

8 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Maintenance Costs

After 6 years' occupancy, there is only a small difference in maintenance costs between the two types of units. The MHUs cost $99 more per unit for maintenance (ignoring equipment costs, such as ranges and dishwashers). This is a 28.5 percent difference in costs ($446/year for MHU vs $347/year for CBU).

Energy Costs

MHUs cost more than CBUs for energy used—$31 more per unit per year for gas and electricity.

Total O&M Costs

The total difference in O&M costs of $130/year/unit (8.6 percent) is not considered significant (based on $1509/year for CBUs ignoring equipment costs.)

However, the maintenance cost difference of 28.5 percent, combined with the overall trend for MHU costs to increase at a faster rate, indicates that the maintenance cost difference may well become significant.

Recommendations

Continue data collection for another year.

APPENDIX A:

DESCRIPTION OF THE MHU CONSTRUCTION PROCESS

The MHUs were not typical of manufactured housing in that the manufacturer was not allowed to design the housing. Instead the contractor was given designs based on the fourplexes being built using conventional construction methods and was required to manufacture accordingly. Thus, it is possible that given the opportunity to both design and manufacture, the final structure might be somewhat different and less costly.

The concept used was to manufacture complete modules in the factory which could be transported (about 200 miles from the factory in the Los Angeles area to Fort Irwin) and assembled on site. Thus, the process involved several steps: manufacture of complete modules (electrical, plumbing, HVAC, etc., included at the plant); construction of perimeter footings at the site; transportation of modules to the site; assembly of the modules into fourplexes using a crane; joining modules together including connection of piping and electrical wiring; application of stucco exterior finish; roofing at the module joints and securing of eaves; and on-site construction of the garages. On-site construction was limited by contract to foundations, utilities, slabs, garages, exterior finishes, final painting, exterior stairways and balconies. Figures A1 through A6 show factory work, modules on trucks, crane assembly and a completed fourplex without stucco and garages.

As is discussed in Chapter 10, the eaves were attached using flat metal straps and folded onto the roof for transportation (this decreased the width for highway transportation). Upon assembly at the site, the eaves were folded down and secured with only a few nails. This was a defect in the design/construction, as the eaves began to loosen and one actually fell to the ground. All eaves were then permanently secured at a cost of over $6000 per building.

The MHUs are essentially the same as the CBUs; floor plans of the two types are very similar. Figures A7 through A10 show sample floor plans for the MHUs and the CBUs.

Figure A1. Construction in the factory.

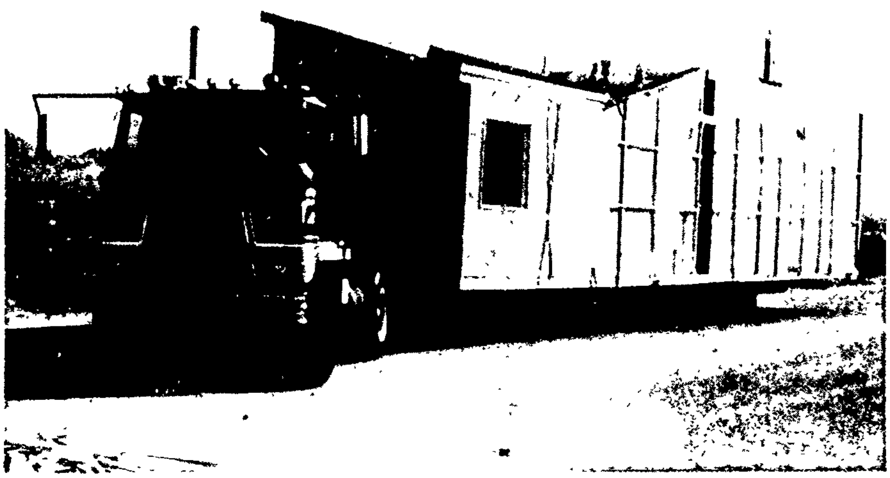


Figure A2. Two modules loaded on truck.

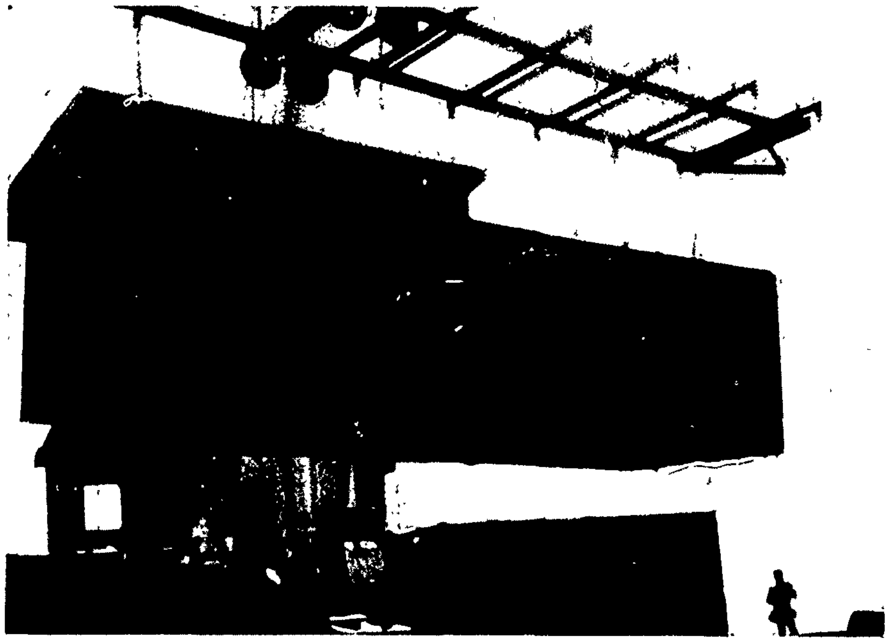


Figure A3. Module being set in place by crane.

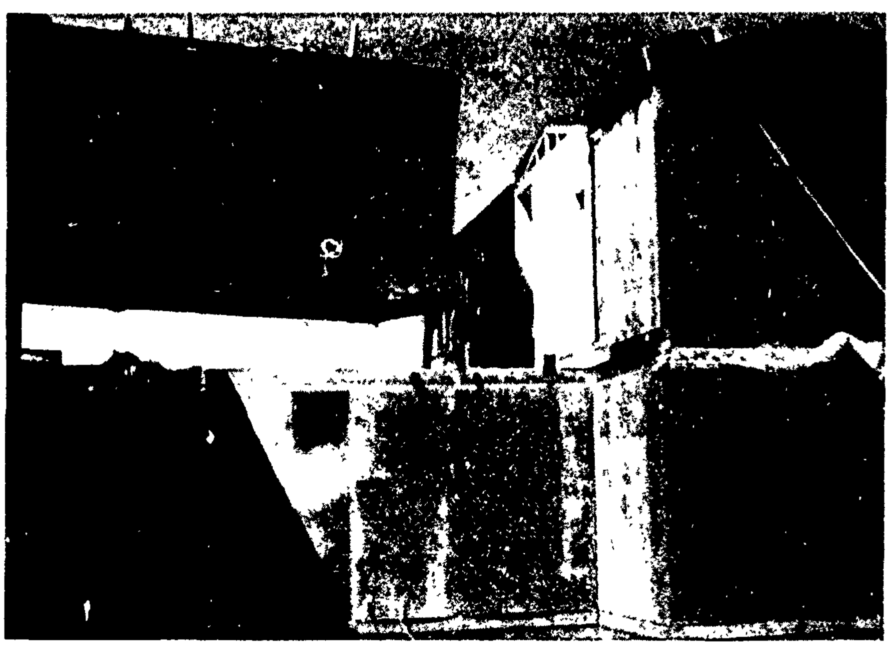


Figure A4. Near completion of one building.

Figure A5. Completed assembly of modules.

Figure A6. Overview of buildings without garages.

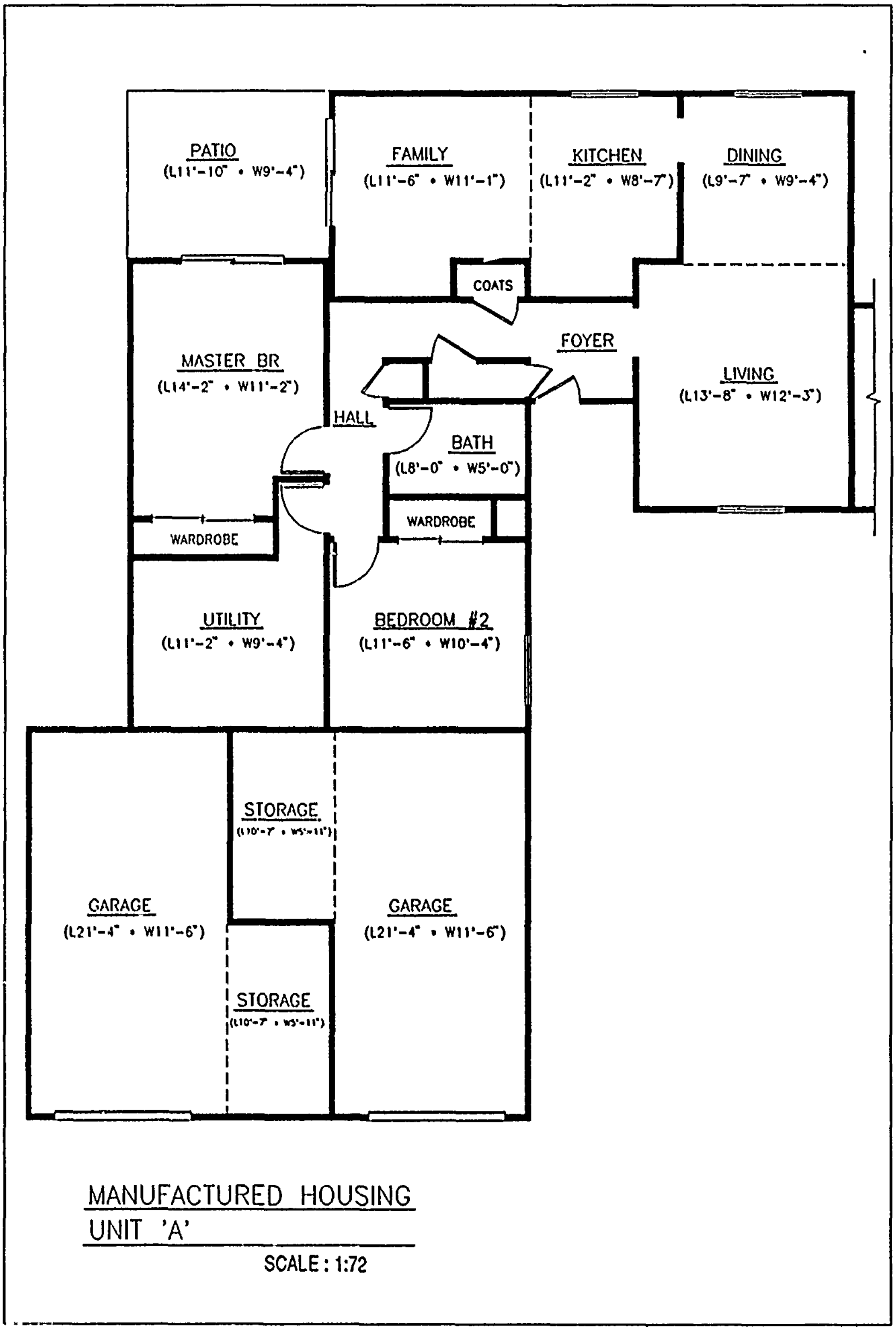


Figure A7. Floor plan for first floor MHU, Type A.

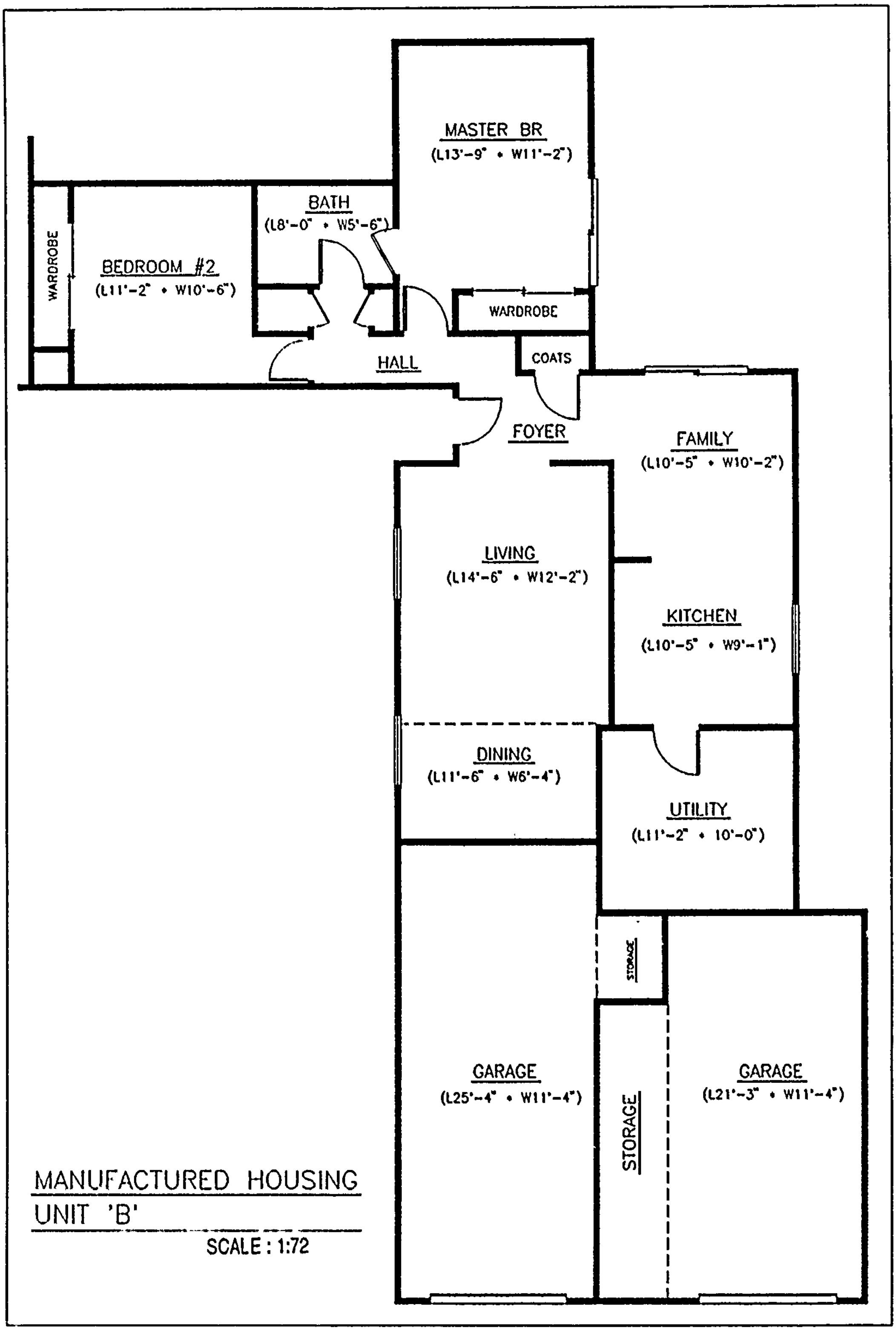


Figure A8. Floor plan for first floor MHU, Type B.

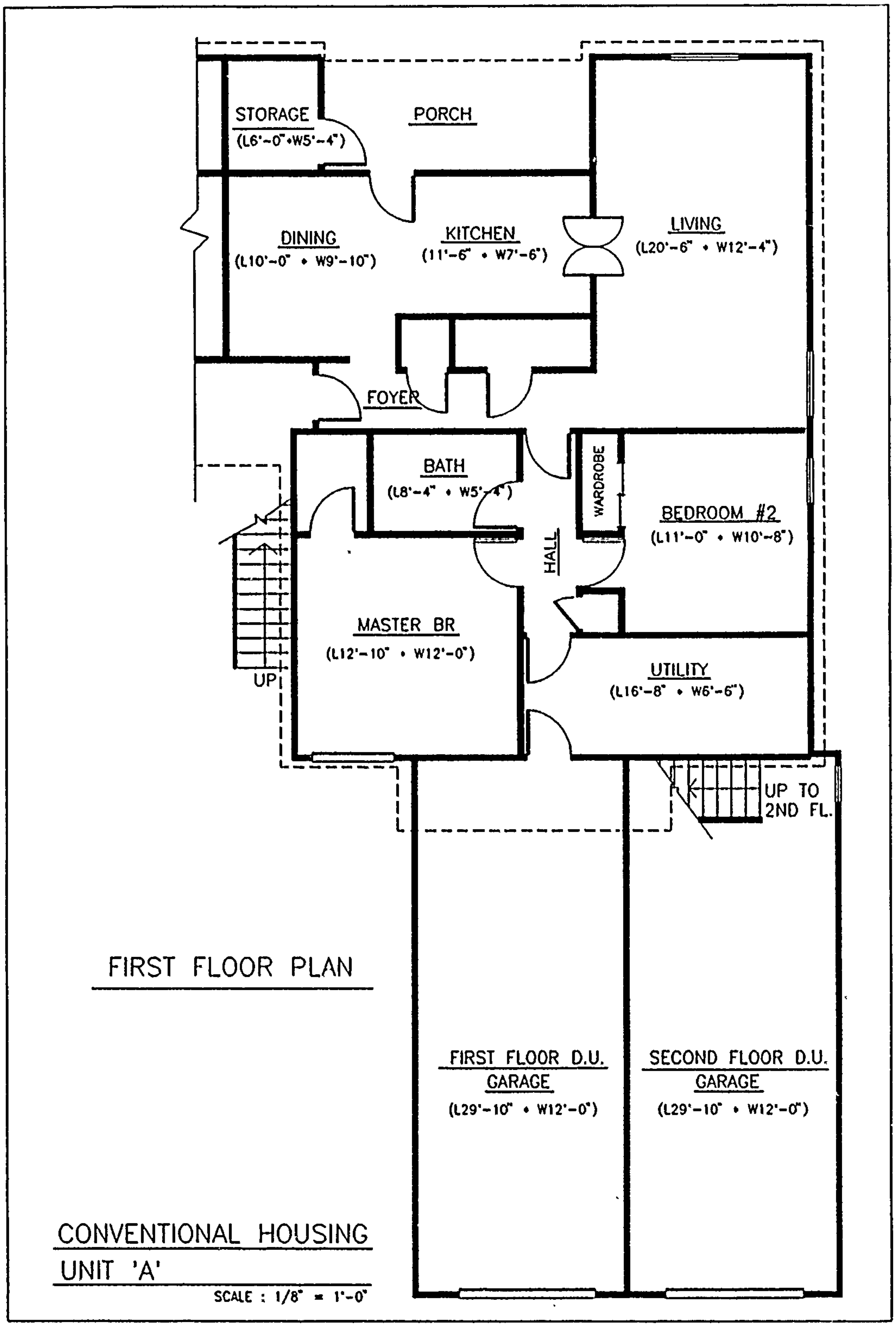


Figure A9. Floor plan for first floor CBU, Type A.

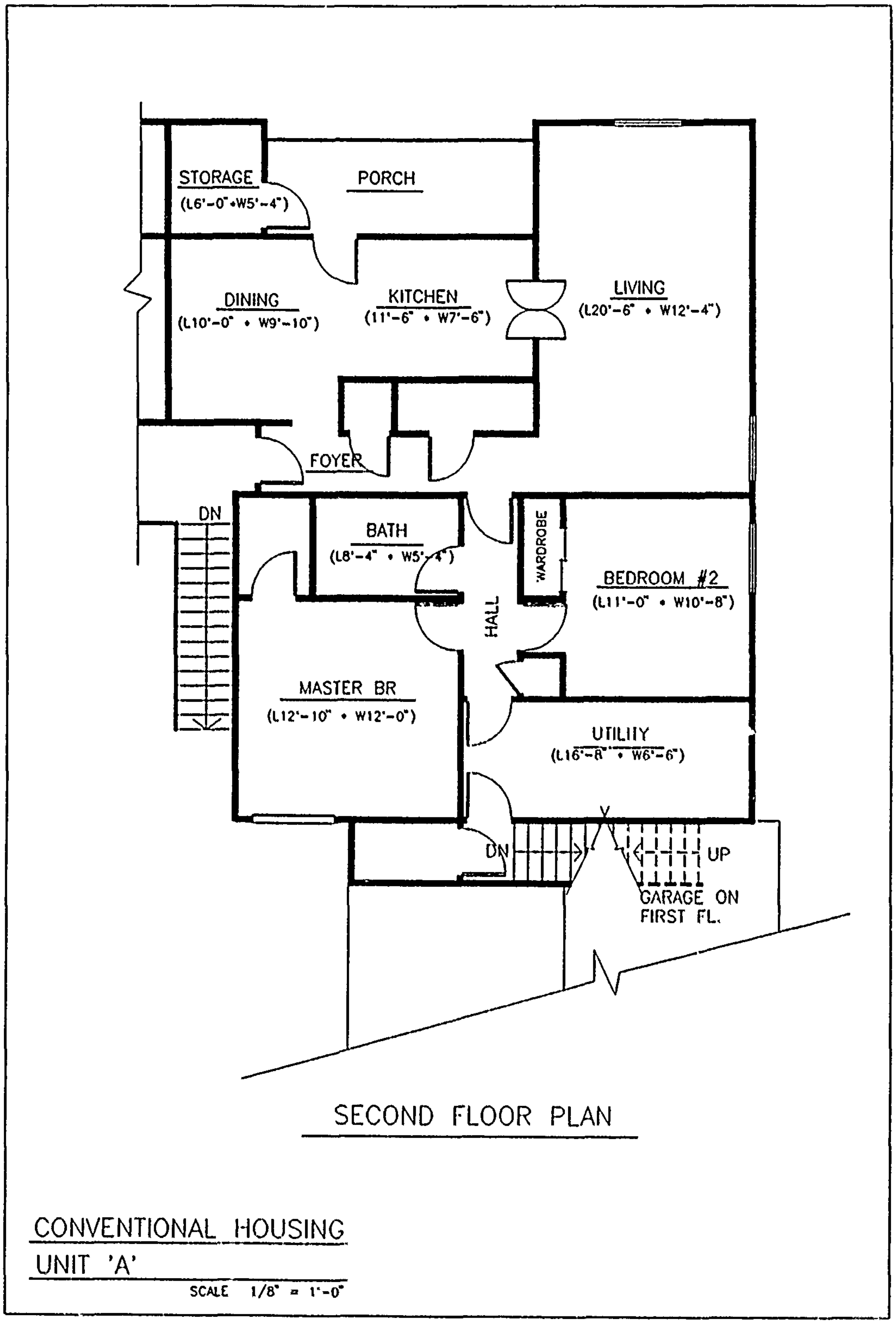


Figure A10. Floor plan for second floor CBU, Type A.

APPENDIX B:

LIST OF HOUSING UNITS

Conventionally Built

3680 A-F	3705 A-E	3727 A-E
3681 A-D	3712 A-F	3731 A-D
3684 A-D	3715 A-F	3732 A-F
3685 A-F	3720 A-F	3738 A-F
3690 A-F	3721 A-E	3742 A-D
3691 A-D	3722 A-E	3743 A-F
3693 A-F	3723 A-E	3745 A-F
3694 A-D	3724 A-D	3747 A-D
3695 A-D	3725 A-E	3750 A-F
3700 A-F		

Manufactured (Each with four apartments, A-D)

3800	3821	3841
3801	3822	3842
3802	3823	3843
3803	3824	3844
3804	3825	3845
3805	3826	3846
3806	3827	3848
3807	3828	3850
3809	3829	3851
3811	3831	3852
3812	3832	3853
3813	3833	3854
3814	3834	3855
3815	3835	3856
3816	3837	3857
3818	3839	3858
3820	3840	

APPENDIX C:

BUILDING COMPONENT/SUBCOMPONENT CODES

01 Roofing

0101	Roofing surface
0102	Fasteners
0103	Flashing, vents, protrusions
0104	Gutter and downspouts
0105	Other roof repairs

02 Structure

0201	Foundation and anchorage
0202	Structure, incl. framing and sheathing, stairs, cracked wall
0203	Insulation and moisture protection
0204	Masonry
0205	Exterior siding, incl. skirting
0206	Exterior doors and frames, incl. hardware and weatherstripping
0207	Storm and screen doors
0208	Window and frames, incl. hardware and weatherstripping
0209	Storm windows and screens
0210	Exterior trim
0211	Porch/deck construction
0212	Interior drywall, incl. fasteners and accessories
0213	Wall coverings and paneling
0214	Interior doors, frames, and hardware, incl. bifold and sliding
0215	Interior casework and finish carpentry
0216	Bathroom accessories, mirror
0217	Kitchen accessories, cabinets
0218	Drapery hardware
0219	Other exterior/interior repair, venetian blinds
0220	Garage door

03 Floor Coverings

0301	Resilient flooring
0302	Carpet and pad
0303	Ceramic flooring
0304	Underlayment/substrate
0305	Other flooring repairs

04 Interior Painting

0401	Walls and ceilings, incl. patching
0402	Trim
0403	Touch-up
0404	Bathtub/shower unit caulking
0405	Other Interior painting

05 Exterior Painting

0501	Walls, siding, incl. skirting
0502	Doors, frames, trim
0503	Exterior trim, incl. window, fascia, rake, soffit, etc.
0504	Caulking and sealing
0505	Glazing
0506	Other exterior painting

06 Heating

0601	Heating plant, valve
0602	Motors, blowers, pumps, G-60
0603	Ducts
0604	Piping
0605	Diffusers, grills
0606	Insulation
0607	Heating controls
0608	Other heating repairs, instructions for thermostat, turn on gas

07 Air Conditioning

0701	Cooling coils, compressor, condenser, valve, contactor
0702	Motors, blowers, pumps, transformer, fuses
0703	Piping, ducting
0704	Refrigerant
0705	Insulation
0706	Controls, delay module, relay
0707	Other cooling repairs, instruct thermostat use, filter

08 Plumbing

0801	Water heater
0802	Water softener
0803	Piping, supply, incl. valves, arrestors
0804	Faucets and shower heads
0805	Lavatories, incl. support and fasteners, caulking

0806	Water closets (i.e., toilets and commodes), incl. support and seals, caulking
0807	Bathtub/shower unit
0809	Other plumbing repair

09 Electrical

0901	Service entrance
0902	Panel box, incl. circuit breakers
0903	Branch circuits, incl. junctions, fasteners
0904	Wall receptacles and switches
0905	Doorbells, chimes
0906	Light fixtures
0907	Vents, fans
0908	Other electrical repair

10 Equipment

1001	Disposal
1002	Dishwasher
1003	Stove, range
1004	Range hood
1005	Refrigerator
1006	Other equipment

11 Utility Plant Equipment

Not applicable

12 Utility Service

1201	Water supply
1202	Gas supply
1203	Electrical service
1204	Sanitary/sewer
1205	Other utility service

13 Miscellaneous

APPENDIX D:

ENERGY EFFICIENCY TESTS OF 15 CONVENTIONALLY BUILT HOUSING UNITS

The objective of these tests was to provide data concerning the energy efficiency of conventionally built housing. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

I. Tests Performed Upon Completion of Construction

Tests were conducted over 4 days in June 1983 on three types of buildings: a fourplex, a fiveplex, and a sixplex. Weather conditions were typical of the high desert area: light to negligible winds, clear skies, low humidity, and temperatures ranging from lows near 70 °F to highs near 110 °F.

House Tightness

A blower door apparatus was used to measure each unit's tightness. The blower door consisted of a variable speed fan, a digital tachometer to measure the fan blade rotation speed, and an inclined manometer to measure pressure differences. The fan could be operated to induce a positive or negative pressure difference in the house with respect to the outdoors.

To perform this test, the fan was fitted tightly into an outside door frame. A barbed fitting which penetrates the blower door was fitted with rubber tubing and connected to one side of the manometer. The other side of the manometer was open to the house. When the fan was operated, it could either force air into the house (pressurized) or force air out of the house (depressurized) depending on the direction of rotation. In either case, the pressure difference between the house and the outdoors could be read on the manometer. The fan speed was adjusted until a specified pressure difference existed (usually 0.1 or 0.2 in. of water). The fan speed required to achieve a given pressure was correlated to air flow, which indicated how tightly the house was sealed.

Each of the units was tested at 0.1 and 0.2 in. H_2O pressurized, and 0.2 in. H_2O depressurized. Some of the more obvious leaks (furnace room doors, dryer vents, attic doors) were then taped, and the house was again tested at 0.2 in. H_2O depressurized.

As shown in Table D1, airtightness was adequate, requiring no corrective work.

Furnace Efficiency

The furnaces in all the units were propane-fired. Tests were performed with a Fuel Efficiency Monitor (FEM), a hand-held automatic flue gas analyzer which measures the flue gas temperature, oxygen content, and ambient conditions and uses this information to calculate and display the percent efficiency of the furnace.

Each housing unit was first cooled down to allow the furnace to operate. The thermostats in the houses were of the "energy-saving" type, and included night setback and temperature limits. These were

disconnected before each test so that the heating and air conditioning could be manually adjusted. The safety relief on the front of each furnace was covered so that room air would not be introduced into the flue. The furnace was then turned on, and a sample was taken of the intake air using the FEM. A 1/8-in. hole was then drilled in the flue of the furnace. After allowing a few minutes for the furnace to reach steady state, the FEM probe was inserted into the flue pipe and a sample was taken of the exhaust gas. The FEM took 2 to 3 min to calculate the furnace efficiency.

Table D1 shows the furnaces' operational efficiencies.

Wall Heat Transfer Characteristics

A Thermo Flow Energy Meter (TEM) was obtained to test the heat transfer characteristics of the walls. The TEM is an infrared radiometer which displays heat flow digitally in units of Btu/hr/sq ft. It can be used to detect insulation defects and to estimate the thermal resistance of exterior walls.

Due to unfavorable weather, the TEM could not be used to calculate R-values. The device was also useful for detecting insulation voids. No insulation voids were found.

Table D1

CBU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes** Per Hour	Furnace*** Efficiency (%)
3720A	213	11.4	52.6
3720B	181	12.1	61.3
3720C	181	13.1	62.8
3720D	213	12.8	67.2
3720E	304	12.4	71.7
3720F	304	13.2	73.0
3724A	181	11.8	61.9
3724B	181	13.3	62.6
3724C	304	13.0	71.4
3724D	304	15.1	72.3
3725A	181	11.7	61.6
3725B	181	12.8	****
3725C	213	13.9	69.3
3725D	304	13.4	72.7
3725E	304	14.8	****

*These are calculated values based on the wall construction. U = heat transfer coefficient; A = area.

**The following rating of air changes per hour at 0.2 in. water column is based on work currently being done by Mansville Corp. for the U.S. Navy; 0 to 5, objectionably tight; 5 to 10, excellent; 10 to 15, satisfactory; 15 and above merits corrective work.

***Most gas fired furnace manufacturers claim 80 percent efficiency.

****Unable to test furnace due to lack of access to the units.

II. Tests Performed after Five Years' Occupancy

The house tightness and furnace efficiency tests were performed again in May 1988. Results are summarized below in Table D2.

Table D2

CBU Energy Efficiency Data 5 Years After Construction

Unit No.	No. Air Changes Per Hour	Furnace Efficiency (%)
3720A	11.0	58.5
3720B	11.4	68.6
3720C	12.9	65.8
3720D	10.2	70.6
3720E	10.6	74.2
3720F	10.8	59.5
3724A	10.6	68.9
3724B	11.6	57.8
3724C	14.4	67.4
3724D	12.3	70.4
3725A	11.3	66.0
3725B	11.8	24.1
3725C	14.4	68.8
3725D	16.2	67.3
3725E	12.4	74.5

Again, no wall insulation tests were performed because of weather conditions.

APPENDIX E:

ENERGY EFFICIENCY TESTS OF 16 MANUFACTURED HOUSING UNITS

The objective of these tests was to provide data on the energy efficiency of manufactured housing units which will be compared to existing energy efficiency data taken on conventionally built housing units. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

I. Tests Performed Upon Completion of Construction

Tests were conducted on three types of fourplexes; Type I (Building 3809), II (Building 3802), and IV (Buildings 3800 and 3806). The tests were conducted over 4 days in April 1984. The weather during the testing was mild for high desert area; medium to strong winds, overcast skies, low humidity, and temperatures ranging from morning lows of 40 °F to highs near 80 °F.

House Tightness

To measure the tightness of each housing unit a blower door apparatus was used, as described in Appendix D.

Each of the manufactured housing units was tested at 0.1, 0.2, and 0.3 in. of water during pressurization and then tested at 0.1 and 0.2 in. under depressurization. Then air leaks were taped (furnace doors and kitchen vents) and the unit was retested at 0.2 in. during pressurization. During the final day the winds were gusting so high that no consistent manometer reading could be taken, so Building 3809 had no data for air infiltration.

The results of the USACERL testing, as presented in Table E1, demonstrate that the airtightness of all the units except one is acceptable. Unit 3800-C had a significantly higher value than the other units and should have corrective work done to improve its tightness.

During the airtightness testing, several leaks were found. In Type II, Unit 3802-C, serious leaks were found in the door to the furnace room. In Type IV, Units 3800 and 3806, leaks were found while depressurizing around the furnace vents and doors (Unit A in both buildings). Also, leaks were found around sliding doors (Unit 3800-C), kitchen window area (Unit 3806-D), utility outlets (Unit 3800-D), and a crack in the dining room wall (Unit 3806-D).

Table E1

MHU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	296	9.9	75.5
3800B	296	11.5	81.8
3800C	363	18.4	80.5
3800D	363	11.3	82.6
3802A	271	9.0	70.1
3802B	271	10.1	75.1
3802C	370	12.1	81.8
3802D	370	11.3	80.3
3806A	296	8.0	78.2
3806B	296	9.8	77.4
3806C	363	8.7	80.7
3806D	363	10.6	82.2
3809A	249	**	80.9
3809B	249	**	82.0
3809C	336	**	80.7
3809D	336	**	79.6

*These are calculated based on the wall construction. U = heat transfer coefficient; A = area.
**Unable to test airtightness due to high winds.

Furnace Efficiency

The furnaces in all of the units were propane-fired. Tests were performed using a FEM, as described in Appendix D. A carbon monoxide meter similar to the FEM was used to ensure that each furnace's burner was completely combusting its fuel and that there was no unusual concentration of carbon monoxide.

The testing was performed in the early morning hours so there would be a low outdoor temperature to start the furnace. The safety relief on the front of each furnace was taped over to prevent room air from entering the flue. A 1/8-in. hole was drilled into the flue near the furnace. The furnace was turned on and a sample of the ambient air was taken. The furnace was then left to reach steady state (approximately 15 min) and then the FEM probe was inserted into the hole and a sample of the exhaust gas was taken. The FEM took approximately 2 to 3 min to calculate and display the efficiency. Three samples were taken to ensure furnace steady state. The hole in the flue was then taped closed.

The furnace efficiencies are typical for the size and type of furnace installed.

Wall Heat Transfer Characteristics

A TEM, as described in Appendix D, was used to test the heat transfer characteristics of the exterior walls of each unit and to detect insulation defects.

This testing was done in the early morning hours because there must be a constant temperature difference of at least 20 °F between outdoor and indoor temperatures. First the outdoor and indoor temperatures were taken until they appeared steady; next the TEM was aimed at an interior wall and the net heat flow reading was recorded. Then the TEM was aimed at an exterior wall and the heat flow through the wall was recorded. Finally the same measurement was made on the outside of the exterior wall (being sure that the area was shaded from sunlight). These results were used in conjunction with a standardized chart to determine the wall's thermal resistance. After these measurements were taken, the TEM was used to detect areas of high net flow readings, which indicate areas of insulation defects. There appear to be a number of insulation voids in Type I, II, and IV Units.

The UA values were calculated for the units, representing the overall heat transfer for the unit inclusive of walls, windows, doors, and roof (heat transferred from one unit to the next unit was considered negligible). The insulation voids listed in Table E2 were determined when the net heat flow varied by 10 Btu/hr-°F.

Table E2

Insulation Void Locations

Building/Unit	Location of Void
3802A	Void area at upper left corner of window in front bedroom.
3802C	Void area above sliding glass door in dining room.
3802D	Void area at right electrical outlet in dining room.
3806C	Void areas in all wall-to-wall seams (corners).
3806D	Void areas in all wall-to-wall seams (corners).
3809B	Void area at upper right corner of sliding glass door in dining room.

II. Tests Performed After Five Years Occupancy

The house tightness and furnace efficiency tests were performed again 5 years after construction. Results are given in Table E3.

Table E3

MHU Energy Efficiency Data 5 Years After Construction

Building/Unit	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	7.8	75.9
3800B	9.4	80.2
3800C	*	76.3
3800D	10.2	72.8
3802A	9.6	71.2
3802B	10.2	80.4
3802C	10.8	79.1
3802D	*	*
3806A	8.6	79.9
3806B	10.3	77.1
3806C	11.4	79.8
3806D	12.9	76.6
3809A	7.4	78.7
3809B	7.0	73.9
3809C	10.2	79.2
3809D	10.3	78.3

*No test performed.

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